

Automatic segmentation and parcellation of subcortical white and grey matter using DTI in the preterm neonate

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Background

Tractography-based segmentation is a method for mapping structural connectivity in the brain¹ that is both highly reliable and corresponds well to cytoarchitectonic atlases². Preterm birth is a leading cause of cognitive impairment in childhood, and is associated with a spectrum of structural brain abnormalities, most commonly characterised by white matter disturbance thought to arise from aberrant thalamo-cortical and cortico-cortical connectivity^{3,4}. Although tractography-based segmentation has revealed disturbances in thalamo-cortical connectivity in preterm infants at 2 years of age⁵ it is not yet feasible to objectively and reliably perform this technique in neonates without a subjective and time-consuming process of manually labelling the cortex. Using a combination of atlas-based parcellation, tissue segmentation and multi-modal imaging, we aimed to implement a fully-automated pipeline for tractography-based segmentation in preterm neonates for objective, noninvasive mapping of connectivity in major subcortical structures.

Methods

43 preterm infants (median gestational age = 28⁺³, range = 23⁺⁴ – 34⁺⁶) underwent 3-Tesla 32-direction DTI acquisition at term-equivalent age. T1-weighted (MP-RAGE) and T2-weighted (FSE with overlapping slices) anatomical images volumes were also obtained for each subject. Cortical segmentation was performed for the T2-weighted images using an expectation-maximisation approach⁶ with age-appropriate tissue priors from a four-dimensional neonatal atlas⁷. Extracted cortices were parcellated by propagating four large, anatomically-defined cortical labels (frontal, parietal, occipital and temporal) from a population-based, neonatal anatomical atlas using non-rigid registration with the individual T1-weighted images as targets^{8,9}. Labelled cortical segmentations were passed into individual DTI space as target masks for tractography (see Fig. 1). In addition the same non-rigid registration method was used to automatically label the whole thalamus and corpus callosum in each subject. Each DTI dataset was processed with FSL¹⁰; streamlines were propagated from the thalamus and corpus callosum seed masks, which were then parcellated into sub-regions according to the maximal connectivity to each cortical area.

Results

Both the thalamus and corpus callosum were successfully parcellated in all subjects. We identified distinct thalamic and callosal subregions that closely mirror those previously observed in adults and older preterm infants^{1,5,11}. Figure 1B shows population maps of both thalamic (left side shown) and callosal subregions after transformation into a common reference space. Across the cohort, a large spatial overlap (indicated by yellow) was seen in the frontal, parietal and temporal subregions of the thalamus and in frontal and parietal subregions of the corpus callosum demonstrating the robust nature of this technique.

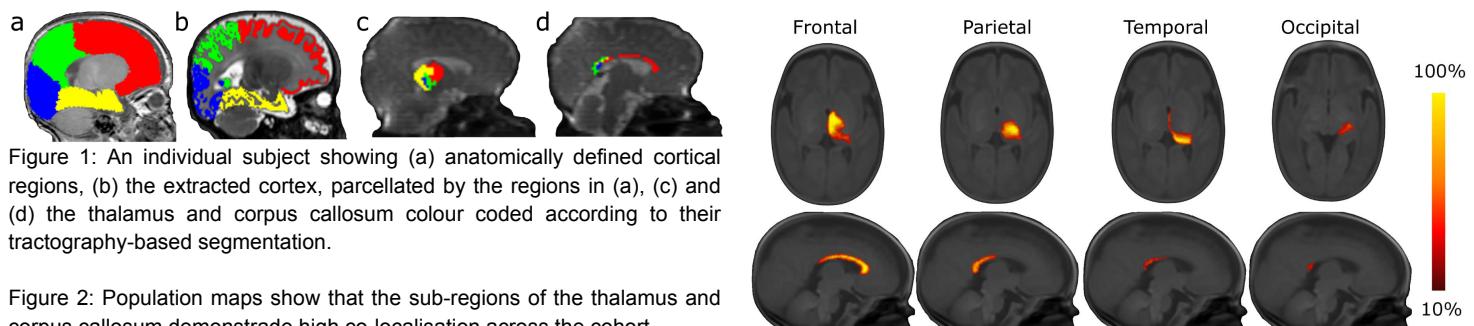


Figure 1: An individual subject showing (a) anatomically defined cortical regions, (b) the extracted cortex, parcellated by the regions in (a), (c) and (d) the thalamus and corpus callosum colour coded according to their tractography-based segmentation.

Conclusion

We demonstrate, using a multi-modal, fully automated processing pipeline, that tractography-based segmentation provides a reliable, non-invasive tool for mapping structural connectivity in the neonate. We propose that this technique will provide a tool for the future study of brain development in preterm infants to further elucidate the nature of aberrant connectivity thought to underlie the common neurocognitive impairment in this population.

References

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